Update on Cosmic Microwave Background (CMB) Thrust

High Energy Physics via CMB temperature and polarization measurements with the South Pole Telescope.

Argonne CMB Detector Development Collaboration between High Energy Physics, the Material Science Division, and the Center for Nanoscale Materials.

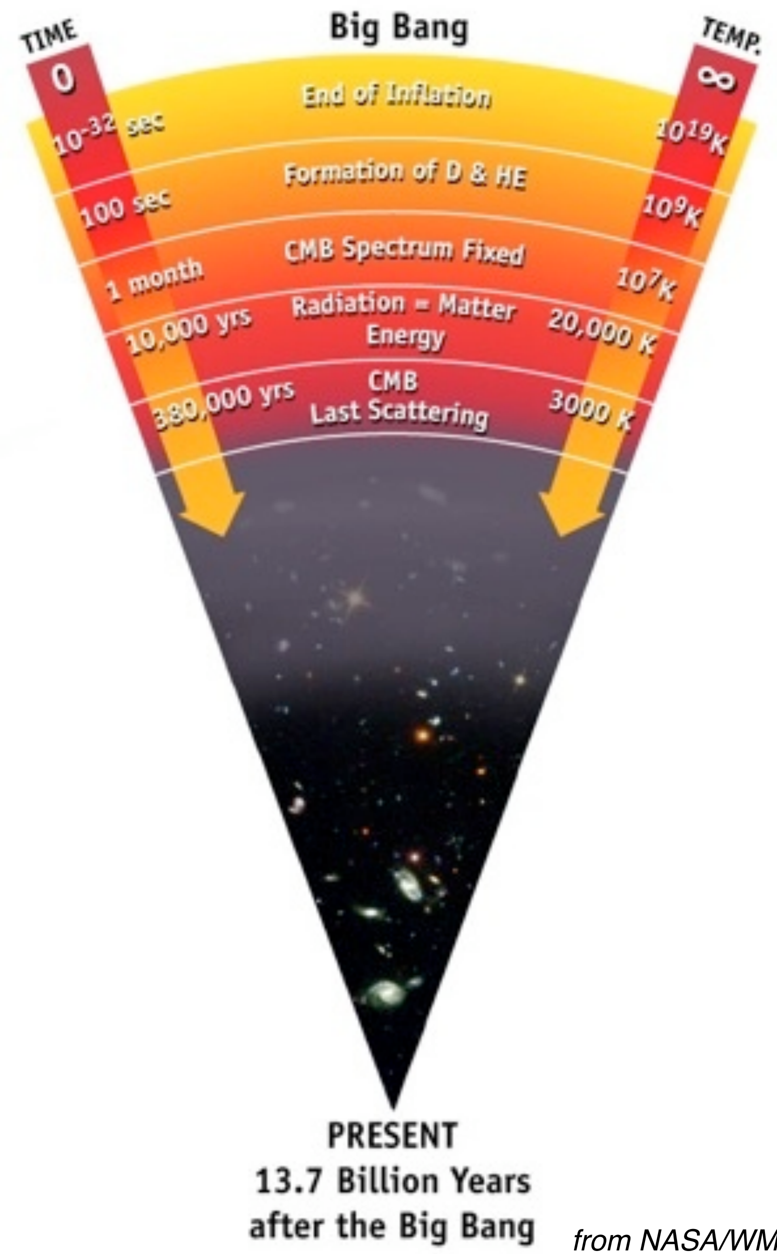
***And with strong University Partners:
University of Chicago/KICP, U.C.Berkeley & LBL, U.Colorado at Boulder & NIST, Case Western, U. Michigan, and McGill University.***

Probing the Cosmic Frontier

We now have a model that describes the evolution of our Universe from a hot and dense state.

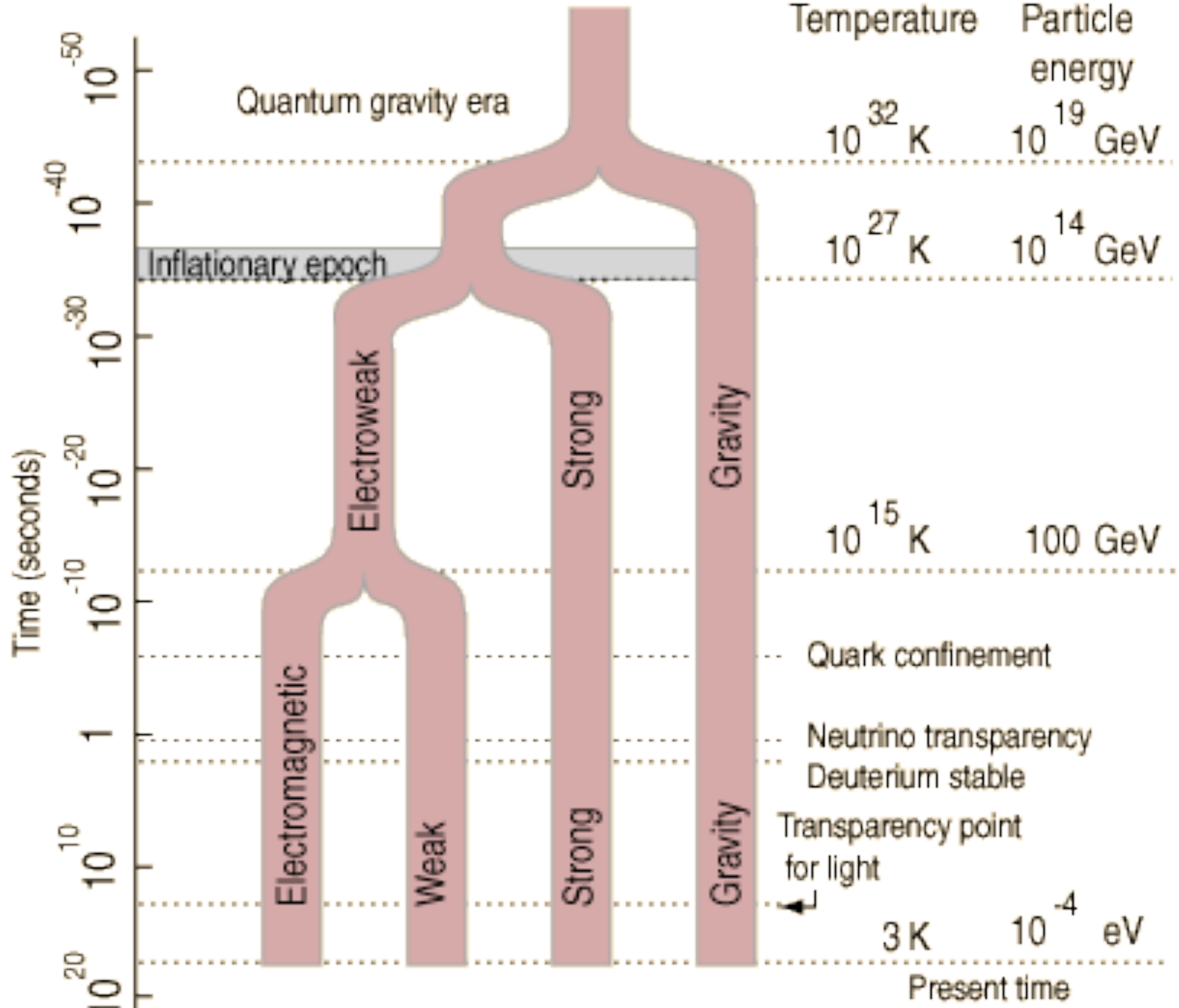
The model has some unusual features ***- new physics -*** Dark Matter, Dark Energy, and starts with a period of Inflation.

Most of the model has been learned from measurements of the cosmic microwave background (CMB).



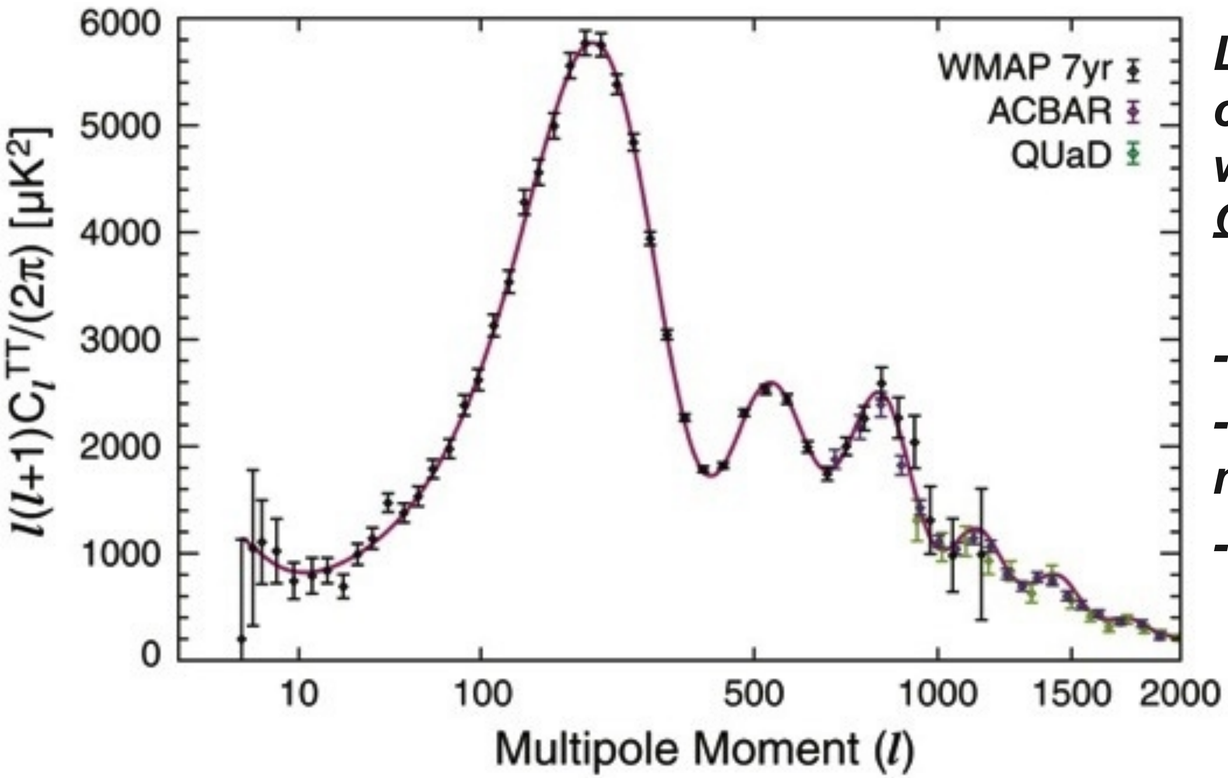
from NASA/WMAP Team

Early universe as an HEP lab



HyperPhysics (©C.R. Nave, 2010)

Incredible progress with CMB



Line is fit to a flat ΛCDM cosmology model with just six parameters: $\Omega_b h^2$, $\Omega_m h^2$, A_s, τ, n_s, Ω_Λ

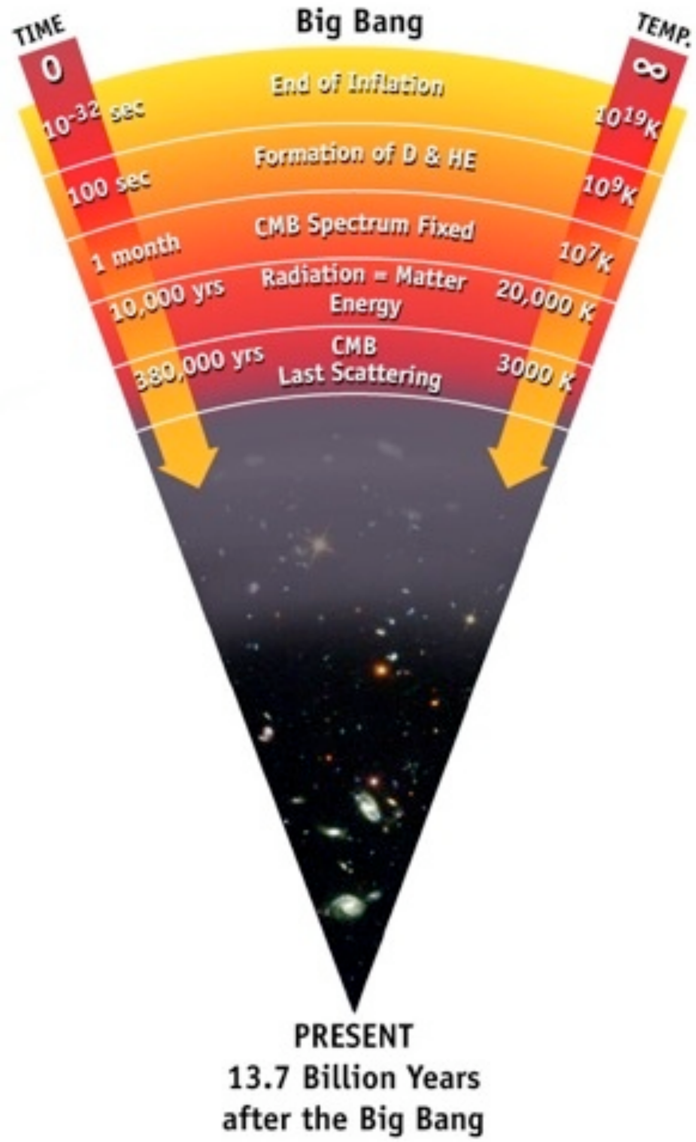
- ***Inflation (flat, n_s)***
- ***Non-baryonic dark matter (3rd peak)***
- ***Dark Energy***

Komatsu et al., arXiv:1001:4538; Larson et al., arXiv:1001.4635

What's next?

A wealth of information remains to be extracted from the CMB

- From intrinsic CMB temperature variations on the sky, especially on small angular scales.
- From small scale distortions to the CMB as it passes through the universe. Evolution of the universe. *Dark Energy*
- From polarization patterns imprinted by gravitational waves generated in the first instants of the universe. *Inflation*



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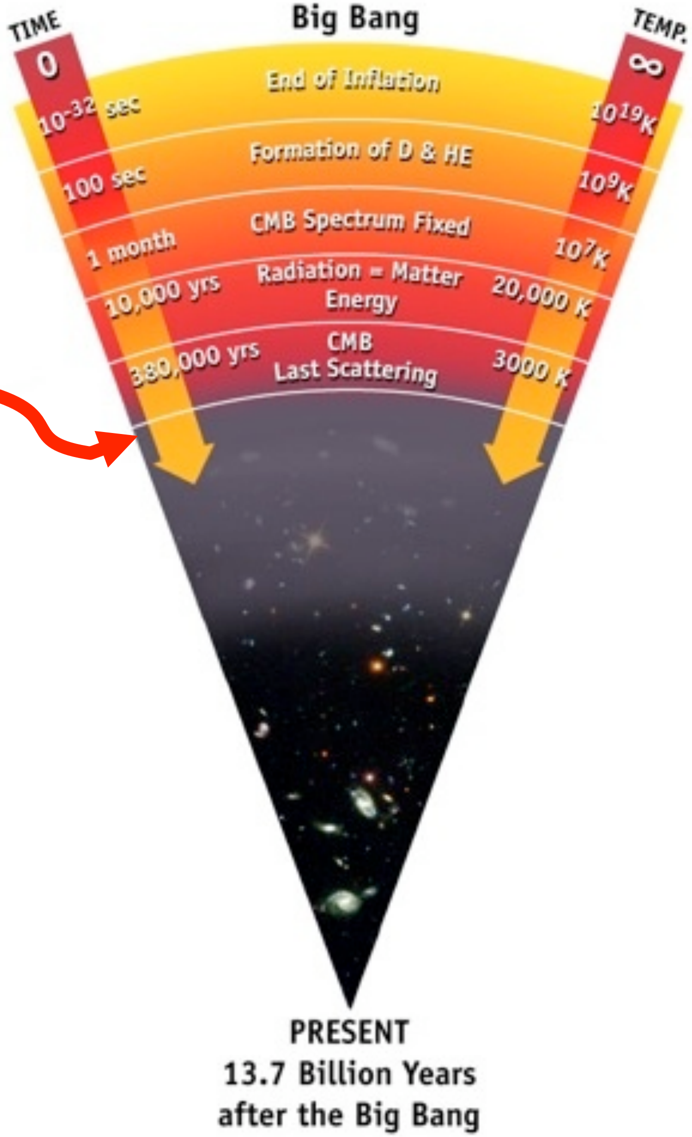
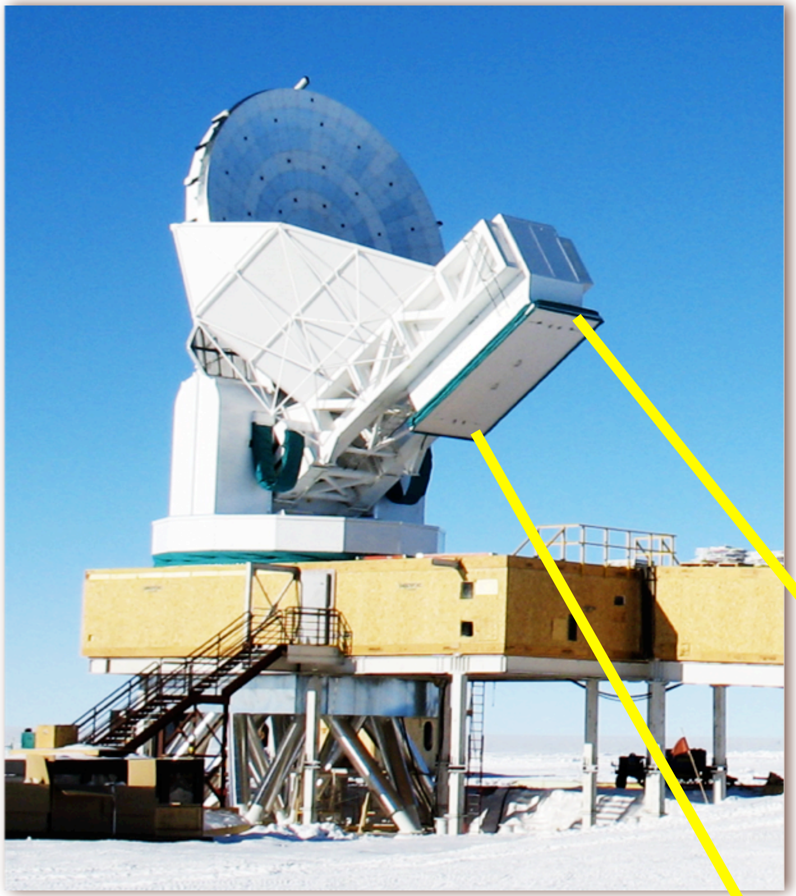
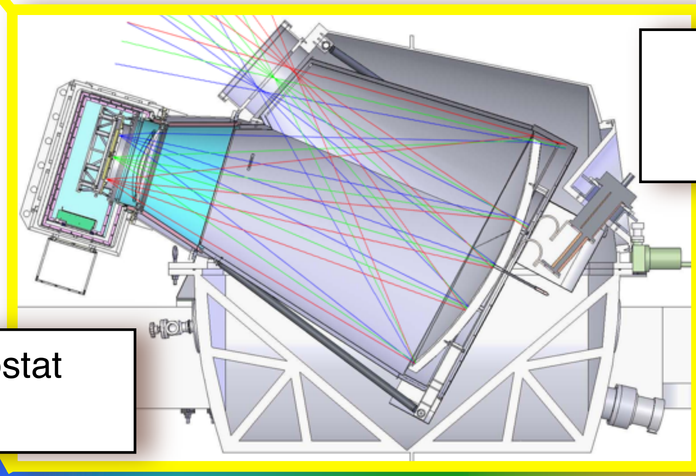


The 10 meter South Pole Telescope



Some Key Features:

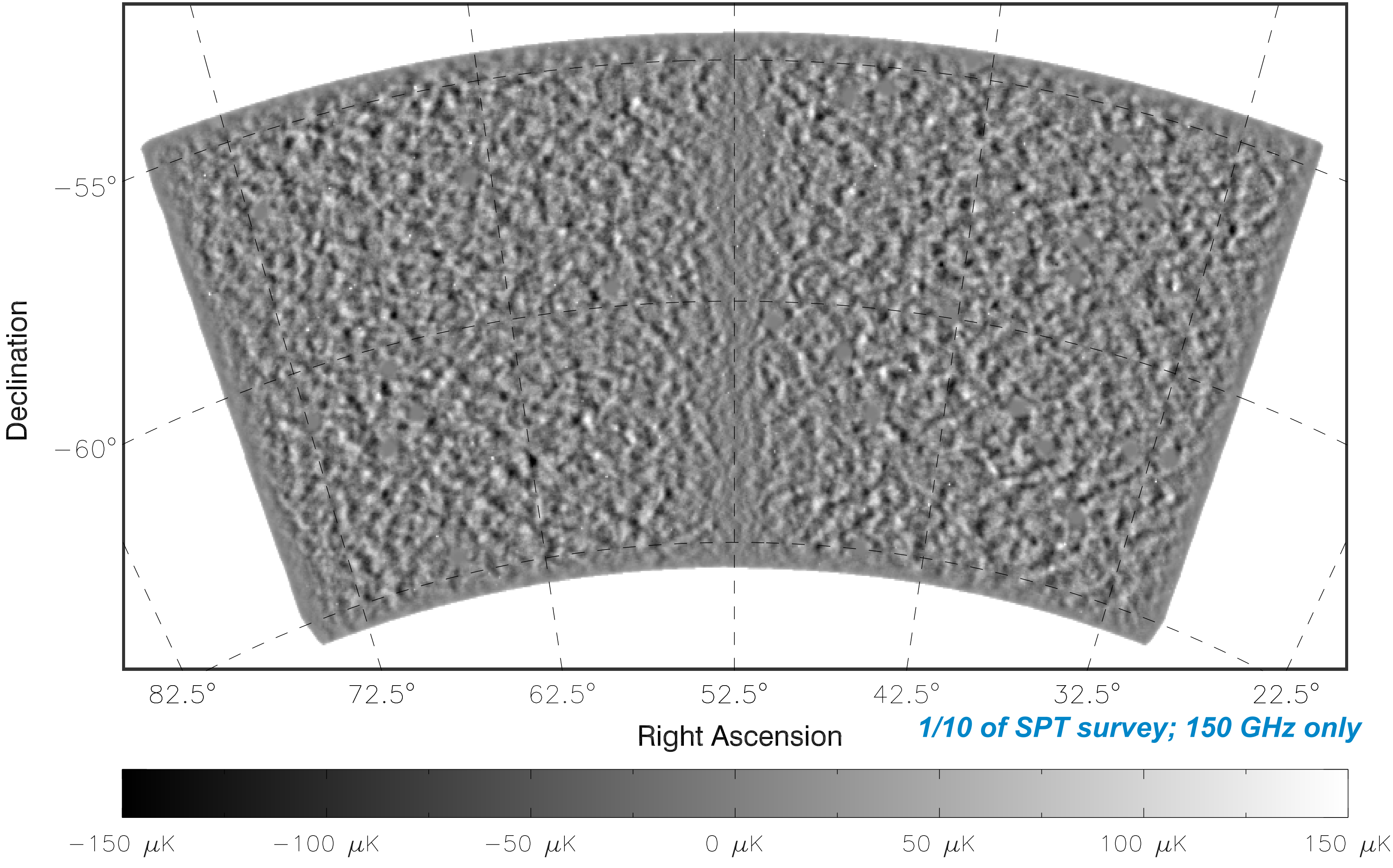
- 1 arcmin resolution at 150 GHz
- 1 deg FOV, unblocked optics
- 960 feedhorn coupled detectors
- Observe in 3+ bands 90, 150 & 220 GHz simultaneously with a modular focal plane
- **Site: fantastic atmospheric transparency and stability, 24/7/52 observing**



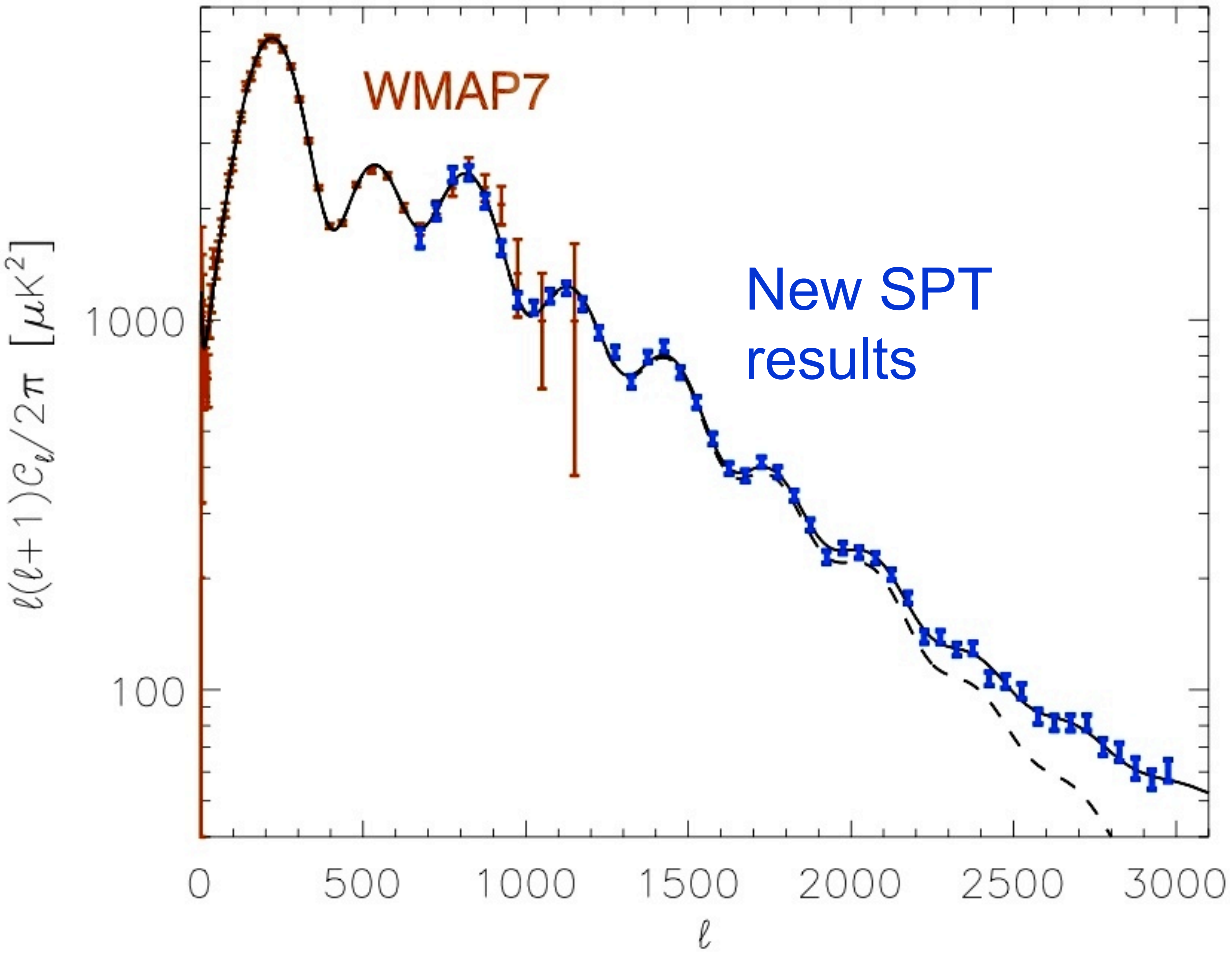
Secondary Mirror cryostat (10 K)

Receiver cryostat (250mK)

Sample SPT map of CMB anisotropy

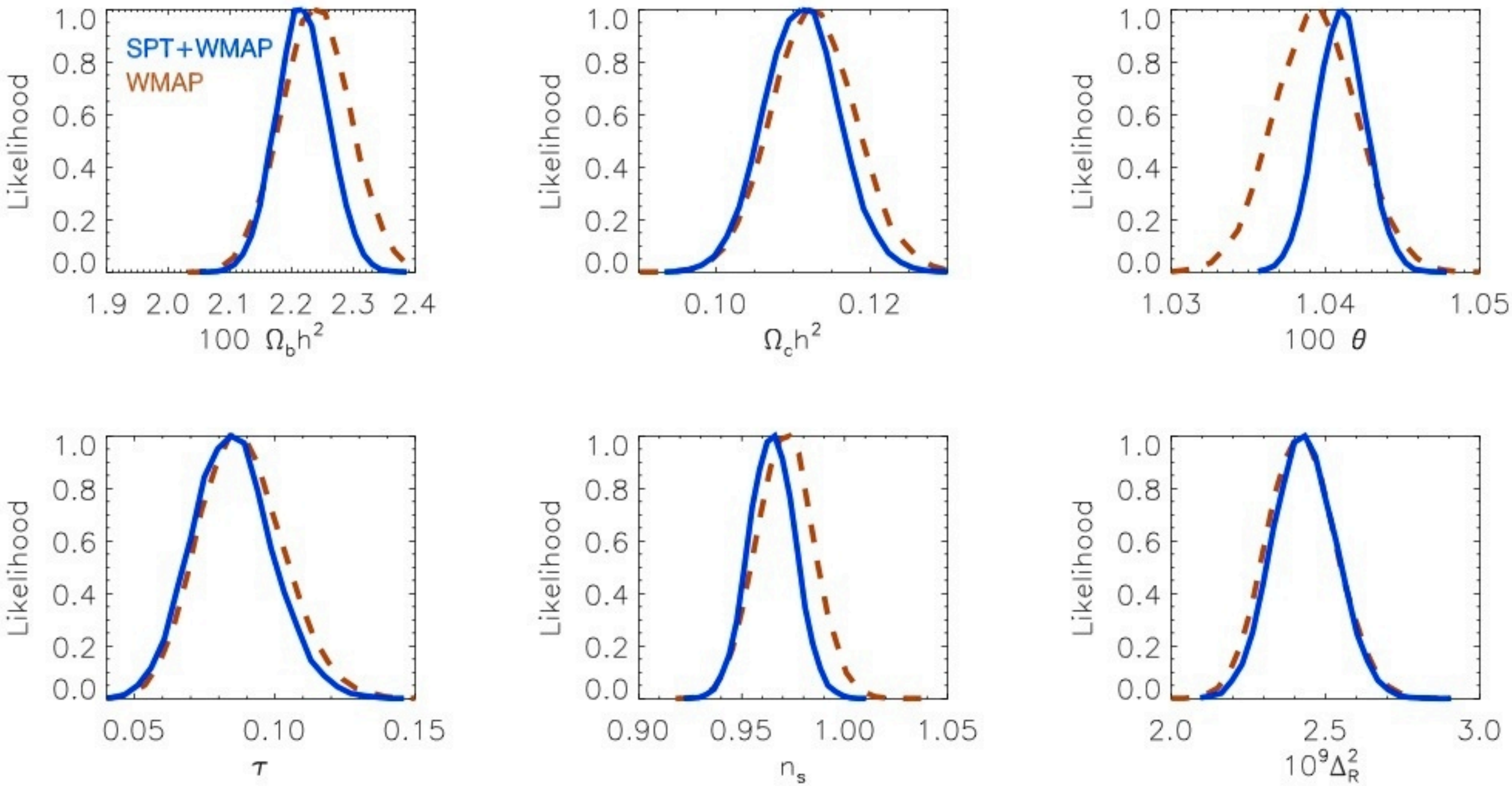


1/10 of SPT survey; 150 GHz only



SPT results: Keisler et al, to be submitted this week!

SPT and WMAP give consistent values for standard ΛCDM 6-parameters, so we fit jointly.



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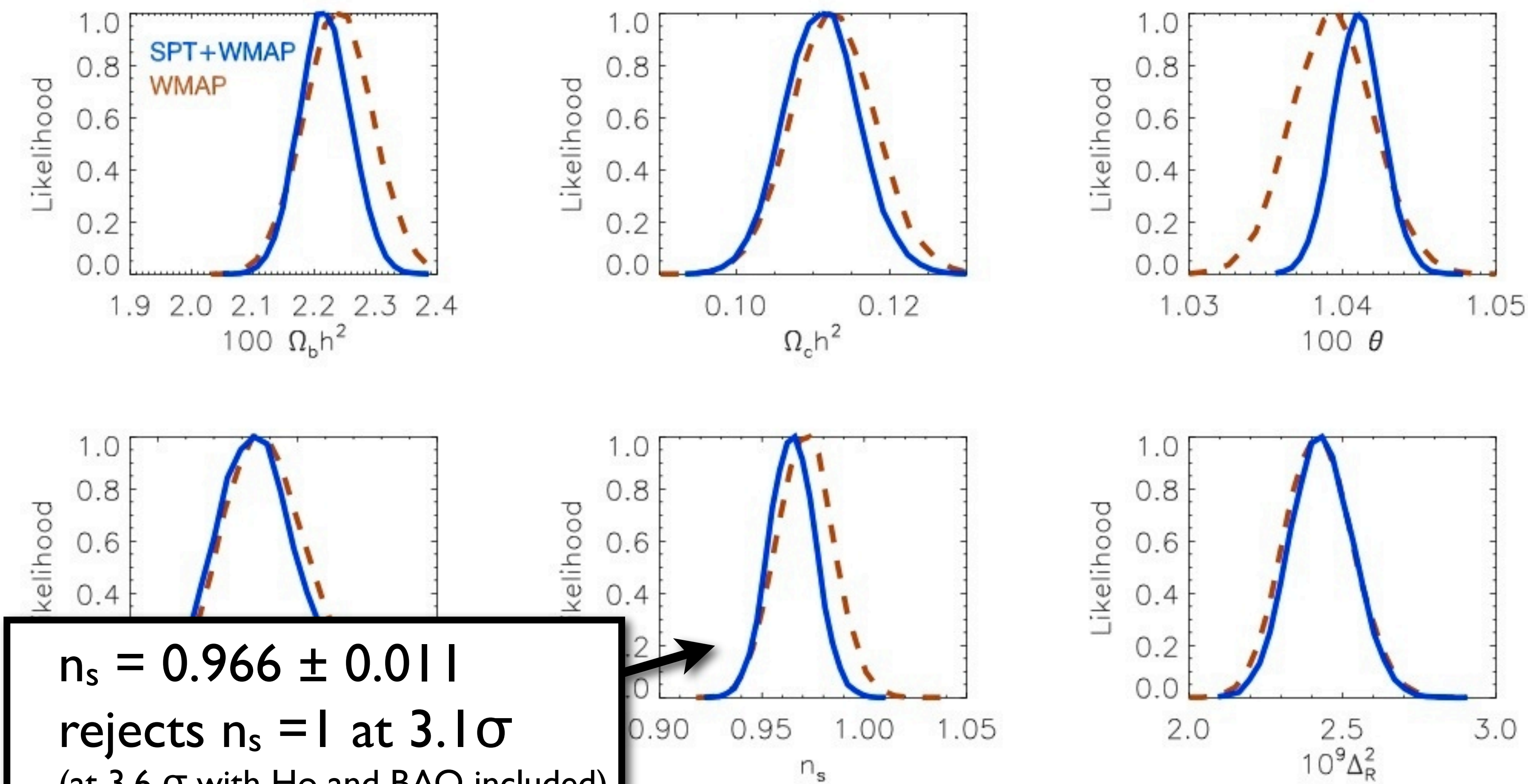


$n_s = 0.966 \pm 0.011$

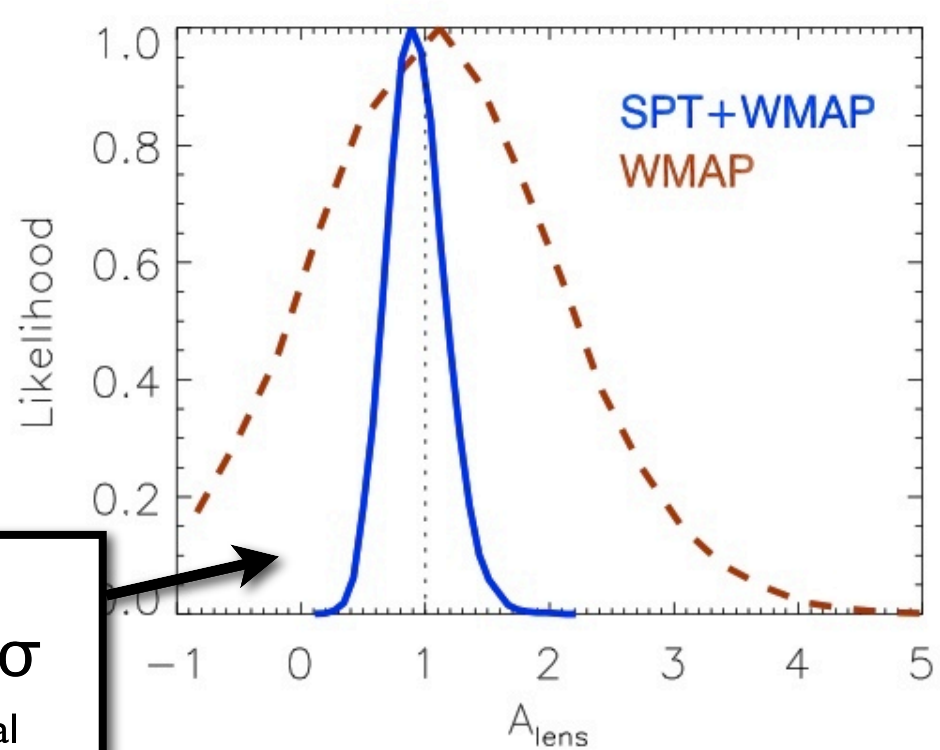
rejects $n_s = 1$ at 3.1σ

(at 3.6 σ with Ho and BAO included)

Going beyond the 6 ΛCDM parameters: fitting an additional parameter

- Gravitational lensing
- Inflation probes:
  - Tensor perturbations, r
  - Running of the spectral index, $dn_s/d\ln k$
- Primordial Helium abundance, Y_P
- Number of relativistic species, N_{eff}

Strong detection of gravitational lensing



$A_{lens} = 0.94 \pm 0.15$

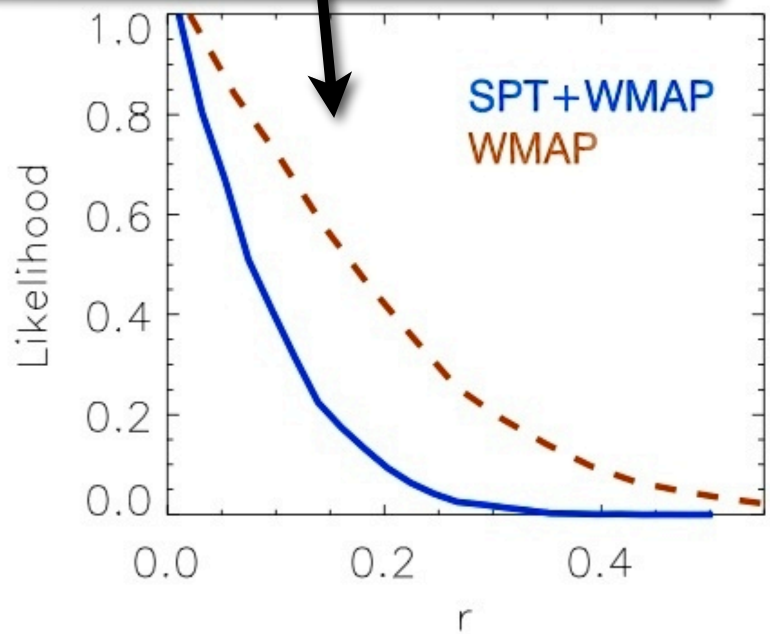
rejects no lensing at $> 5\sigma$

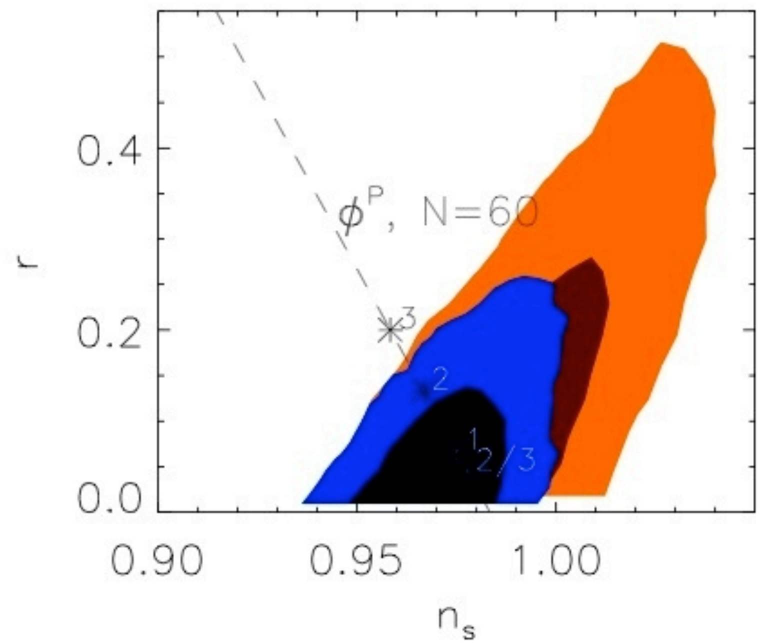
(higher s/n in reconstructed potential power spectrum, VanEngelen in prep)

Lower limit to tensor perturbations

r < 0.21 at 95% CL

(r < 0.17 with Ho and BAO included)

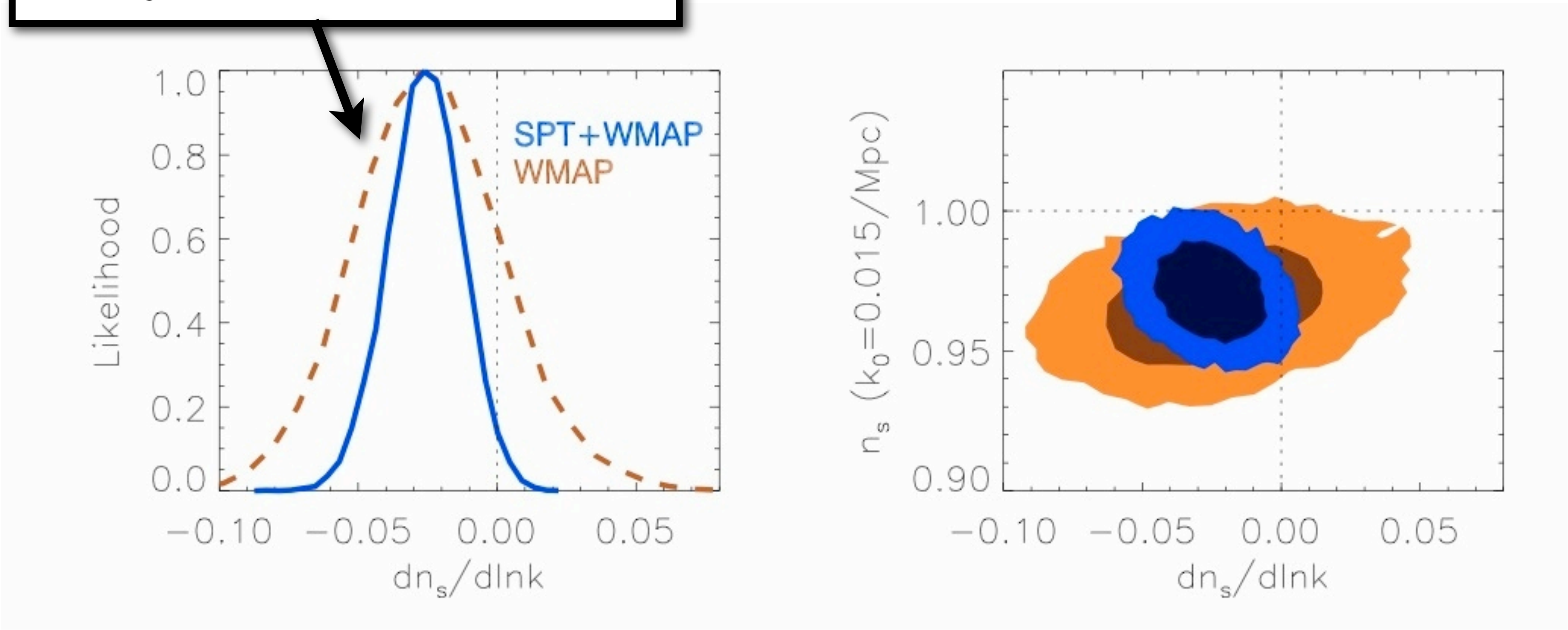




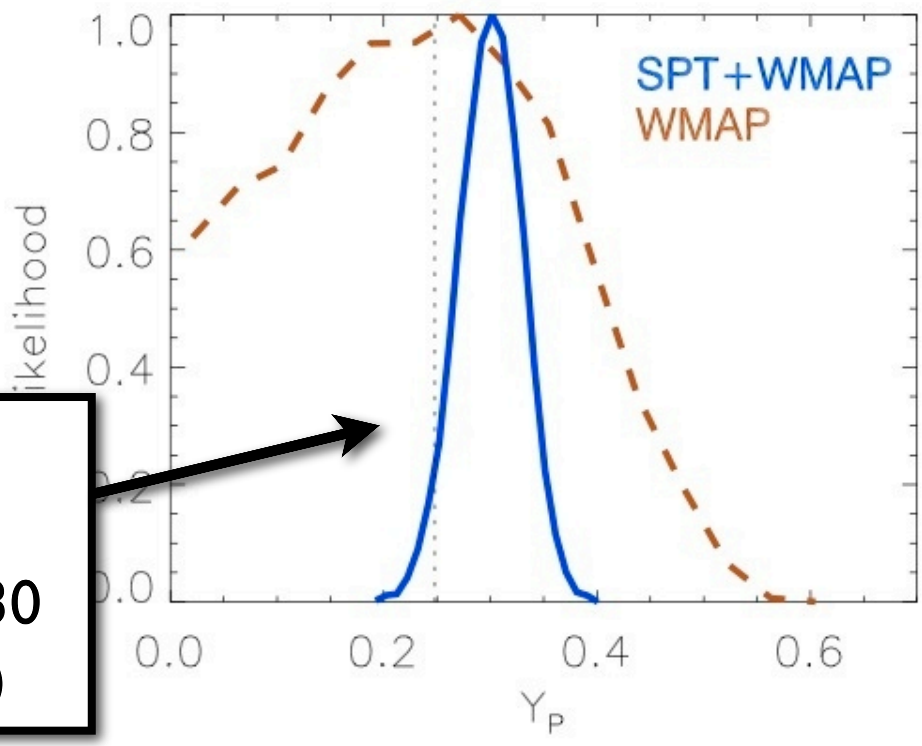
There is lower power at high ℓ

There is lower power at high ℓ
Running of the spectral index?

$dn_s/d\ln k = -0.024 \pm 0.013$



There is lower power at high-ℓ
More damping from Helium?



Primordial Helium
$Y_P = 0$ rejected at 8 σ
prefers $Y_P = 0.300 \pm 0.030$
(1.6σ higher than BBN)

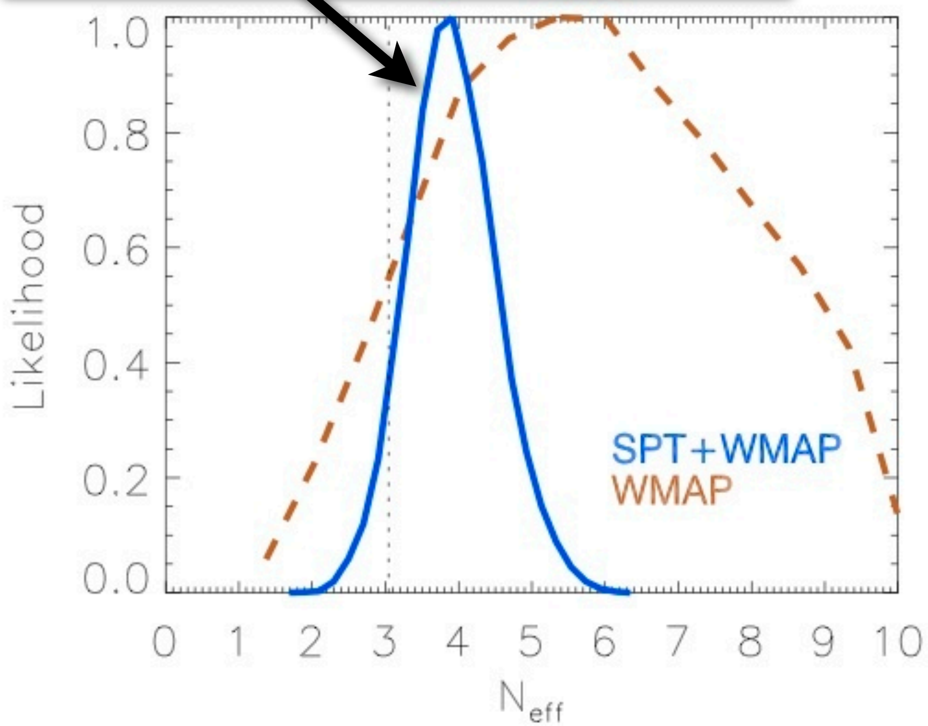
There is lower power at high-ℓ

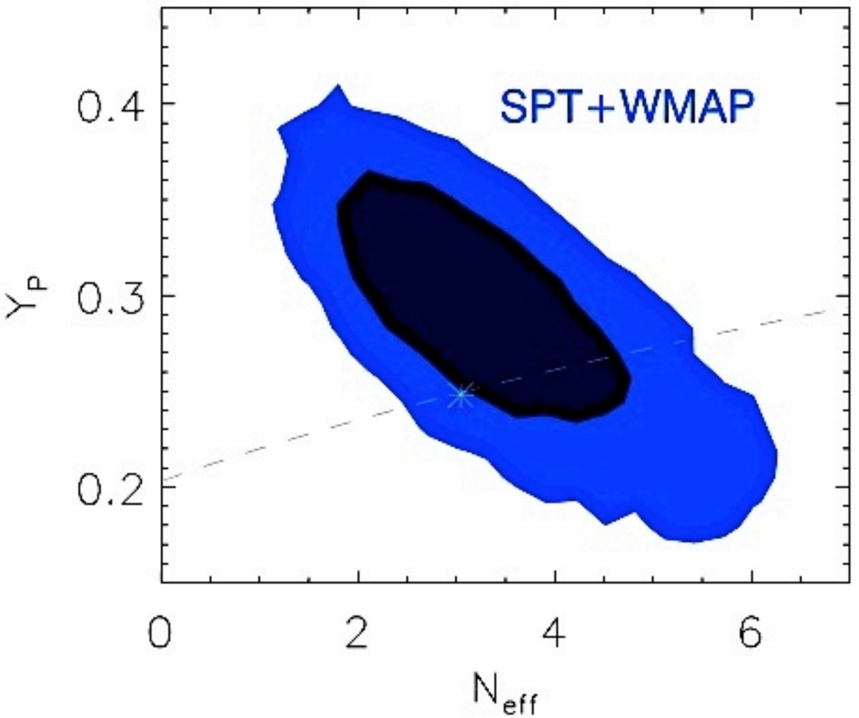
Additional relativistic species, $N_{eff} > 3$?

$N_{eff} = 3.87 \pm 0.61$

rejects $N_{eff} = 0$ at 7.5σ

($N_{eff} = 3.85 \pm 0.44$ with H_o and BAO)





To understand CMB sensitivity to N_{eff}, see Hou et al., arXiv: 1104.2333

There is lower power at high-ℓ

Additional relativistic species?
N_ν pushed to 3 by adding cluster abundance σ_8 constraint

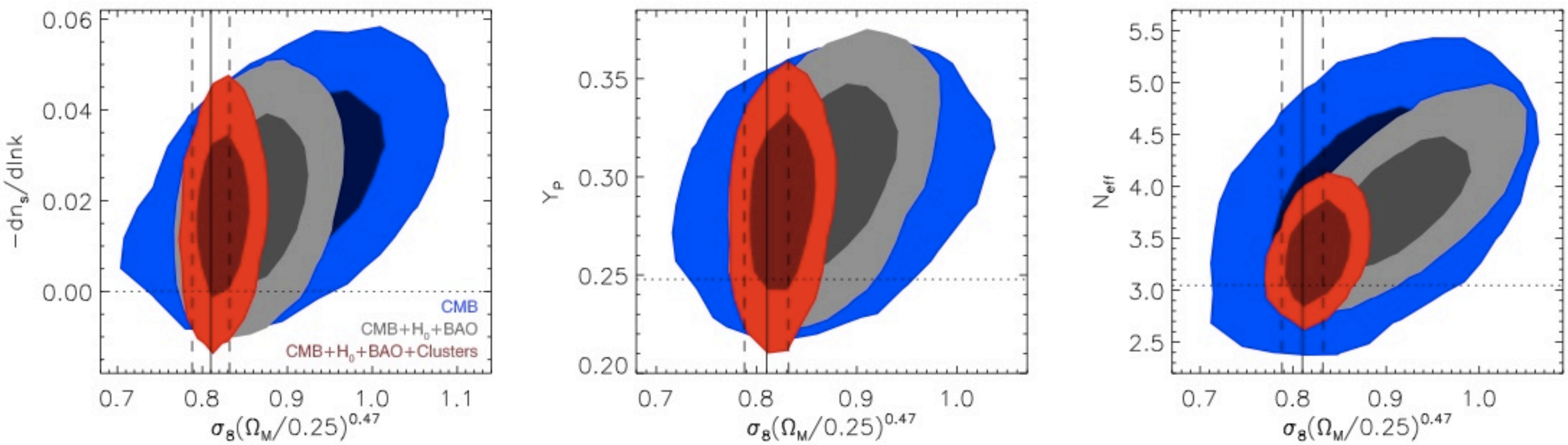


FIG. 14.— The two-dimensional marginalized constraint on spectral running, primordial helium, or the effective number of relativistic species versus the combination $\sigma_8(\Omega_M/0.25)^{0.47}$, which is well constrained by the cluster abundance measurement of Vikhlinin et al. (2009). "CMB" corresponds to SPT+WMAP7. The constraint on $\sigma_8(\Omega_M/0.25)^{0.47}$ from the clusters and the corresponding 1σ uncertainties are shown by the vertical lines. The standard values of the spectral running, primordial helium, and the effective number of relativistic species are shown by the dotted horizontal lines. Adding the cluster abundance information moves the constraints on these parameters closer to their standard values.

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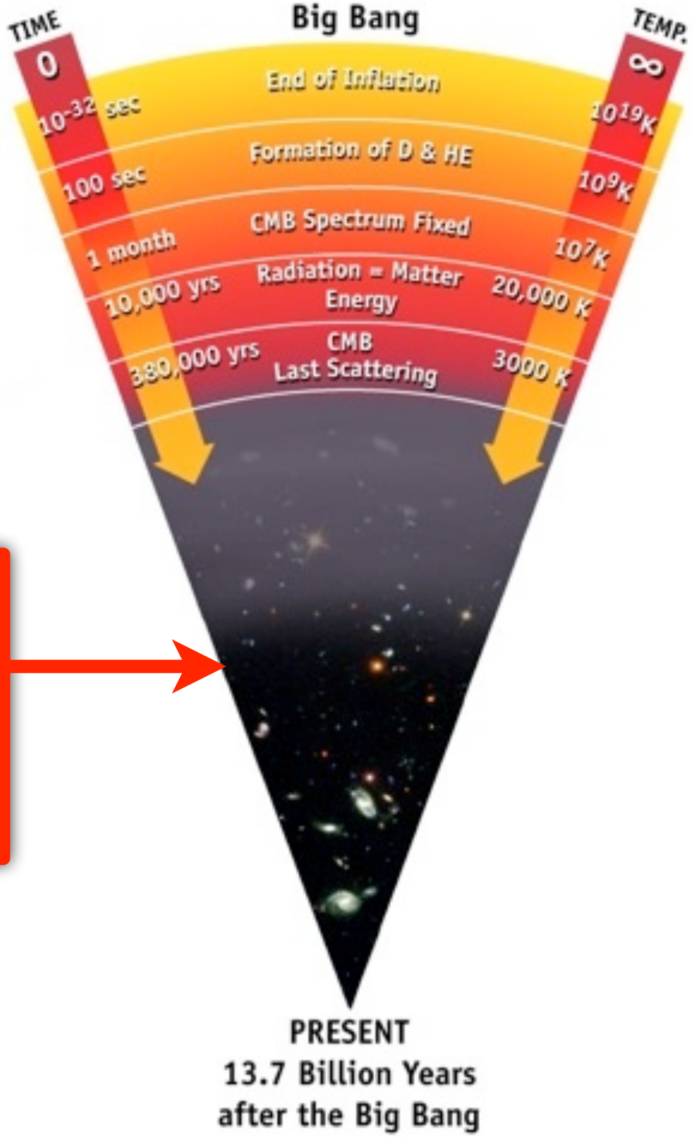
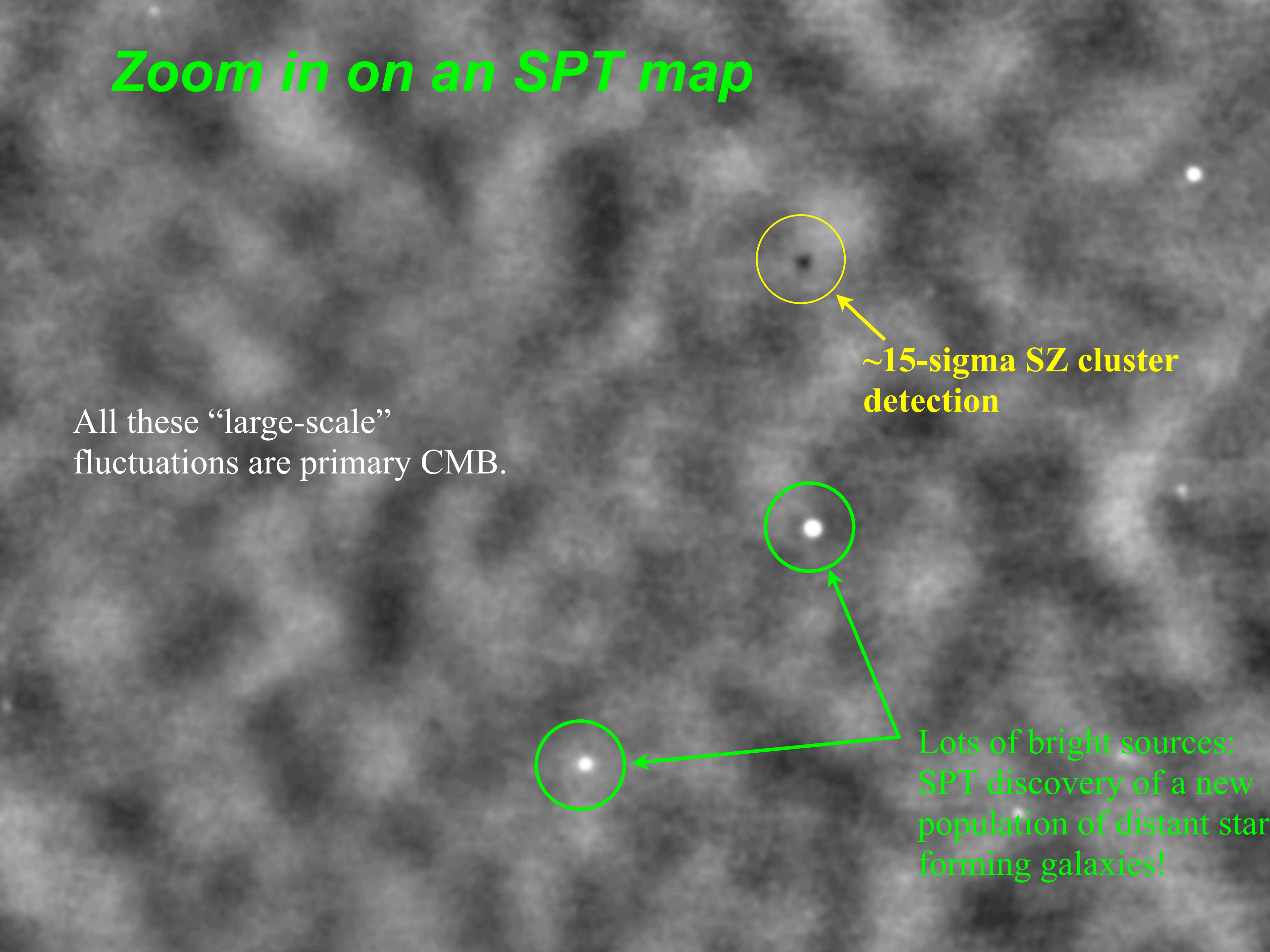
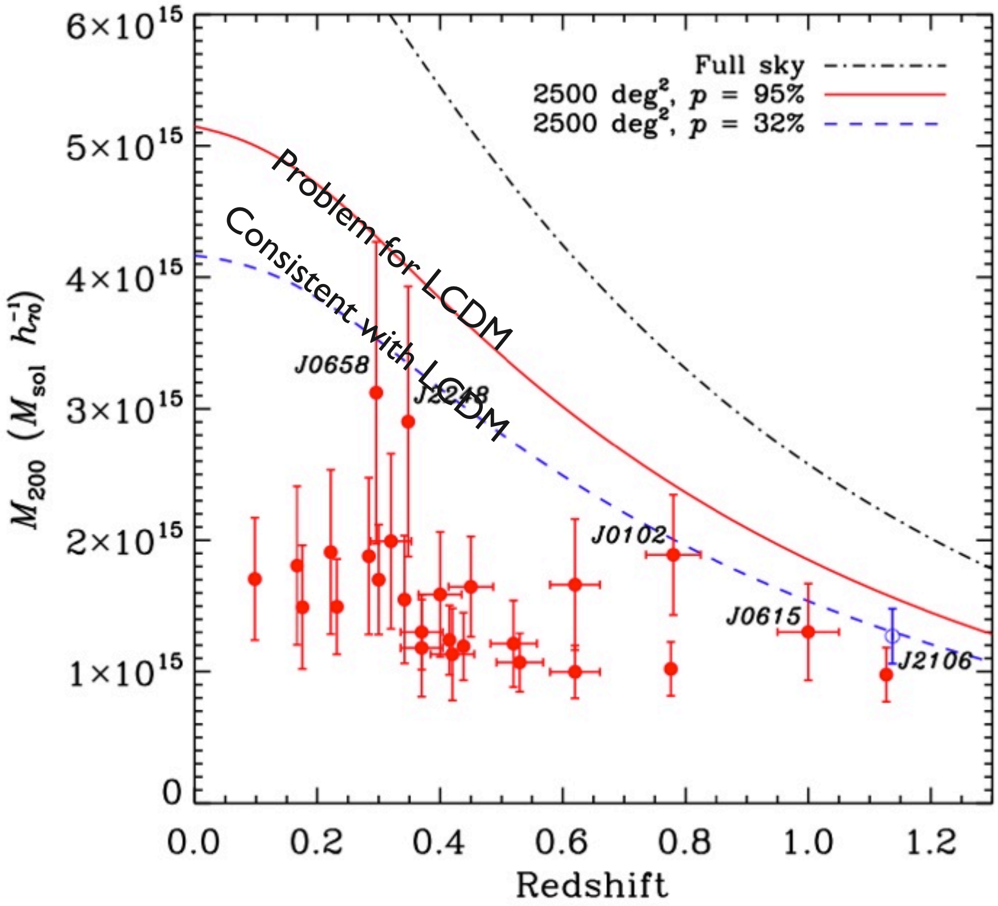


Zoom in on an SPT map



Tests of ΛCDM and Non-Gaussianity



Highest s/n (most massive) clusters over the full 2500 deg^2 SPT survey.

- Probes the extreme tail of the matter power spectrum.
- Even a single massive cluster could indicate tension with ΛCDM (Mortonson, Hu, Huterer 2010).

We find:

- 7% chance of finding J2106
- consistent with ΛCDM and Gaussian initial density fluctuations

Williamson et al 2011, arXiv:1101.1290

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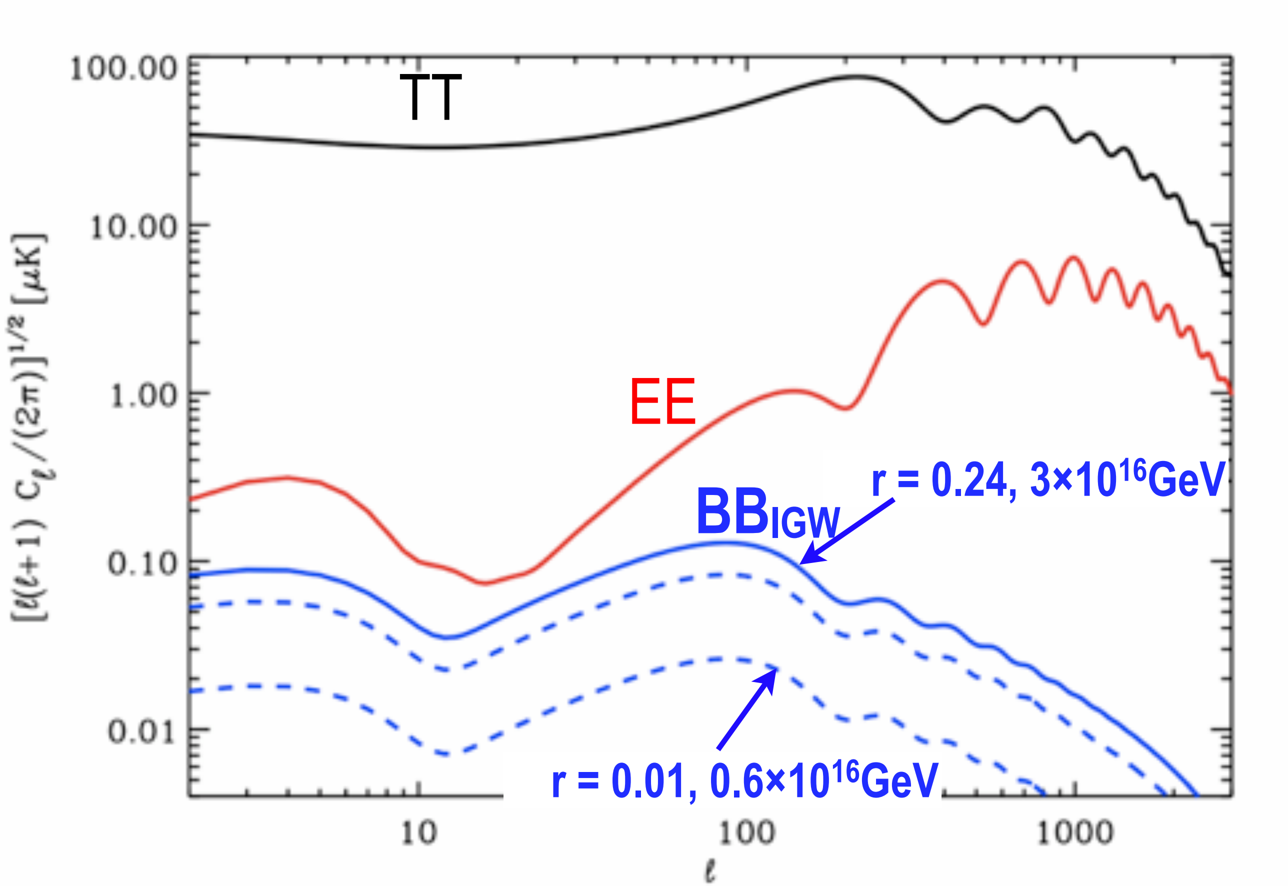
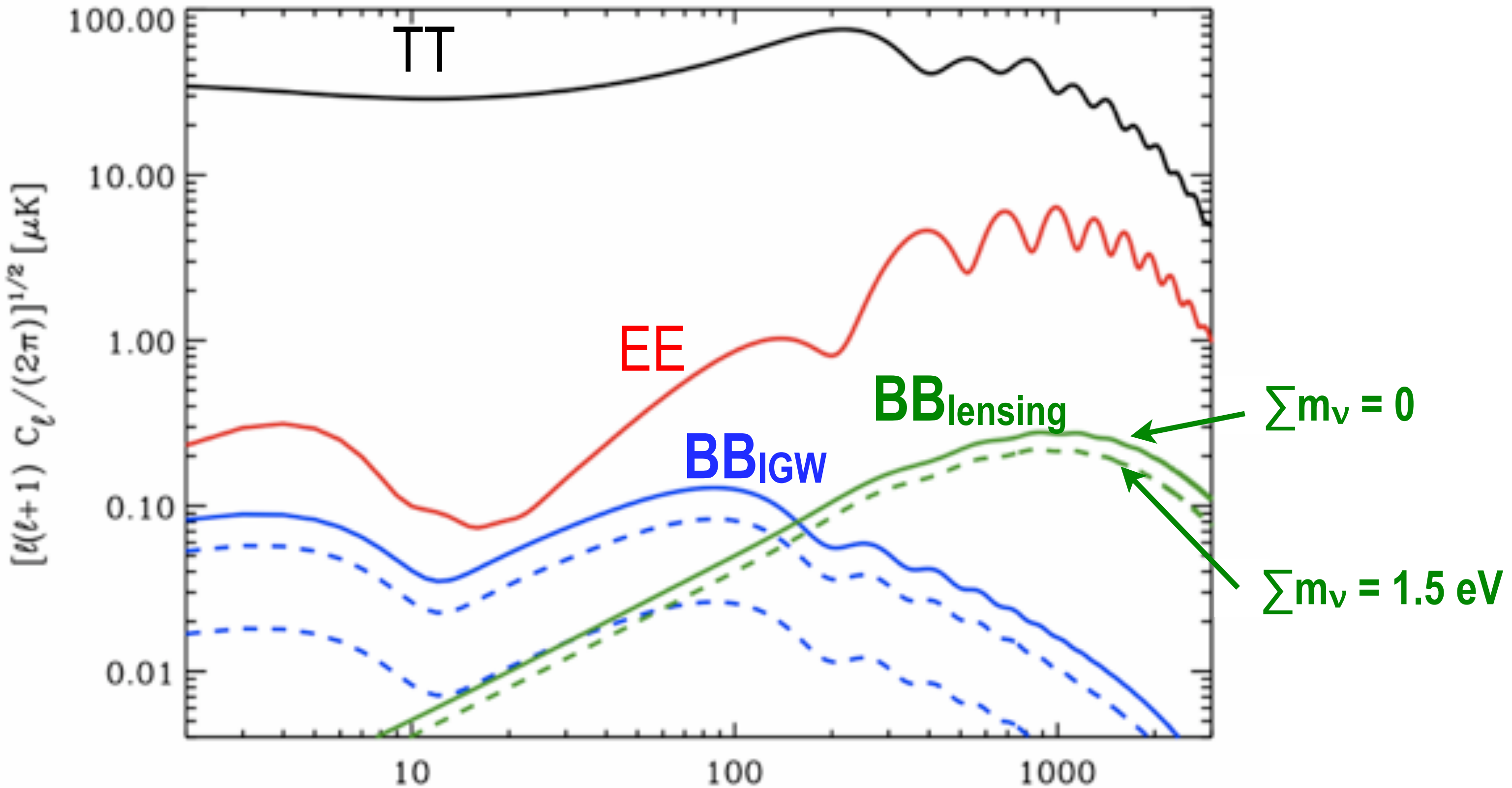
SPT future: CMB polarization



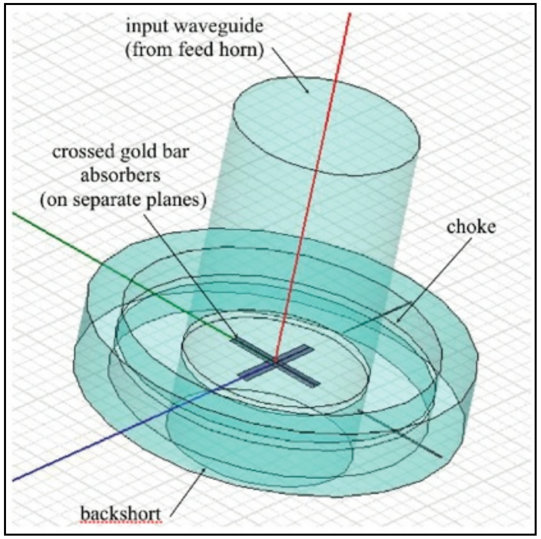
r is the tensor to scalar ratio of the primordial fluctuations

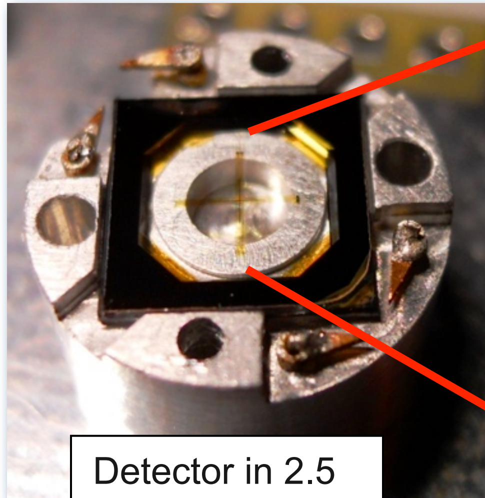
SPT future: CMB polarization



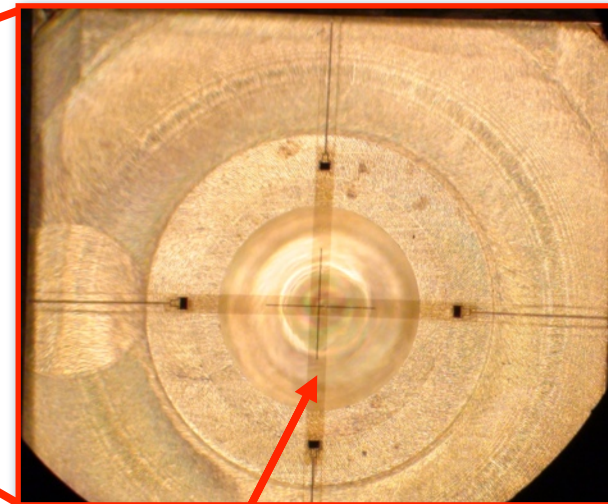
CMB measurements should be able to achieve $\sigma(\sum m_\nu) = 0.05$eV, comparable to Δm measured by neutrino oscillations.

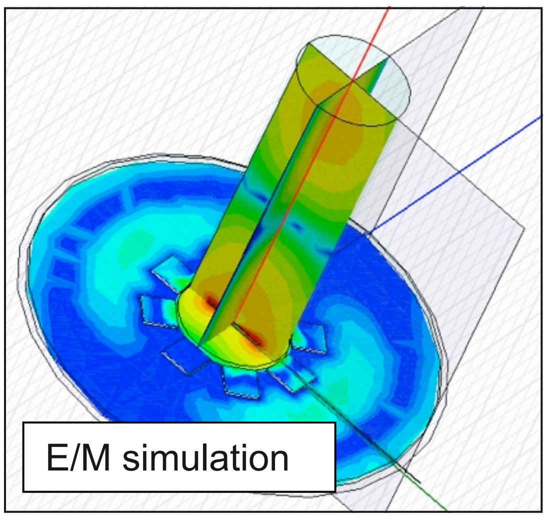
LDRD developed Argonne SPTpol TES Detector



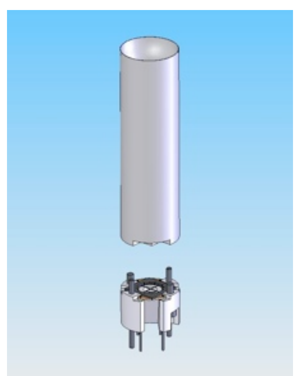


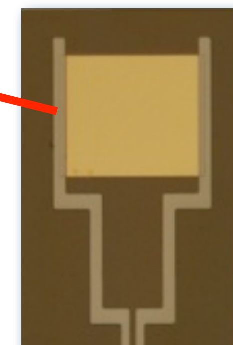
Detector in 2.5 mm waveguide mount





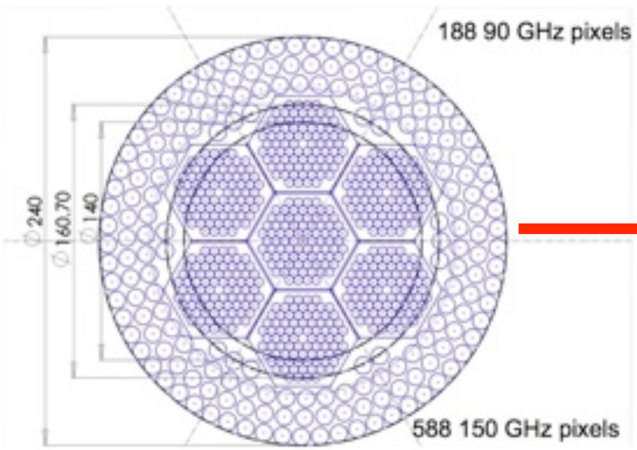
E/M simulation

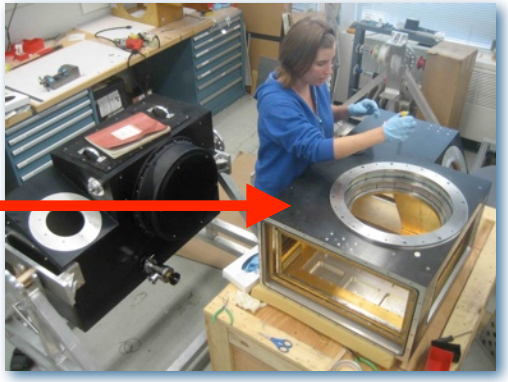


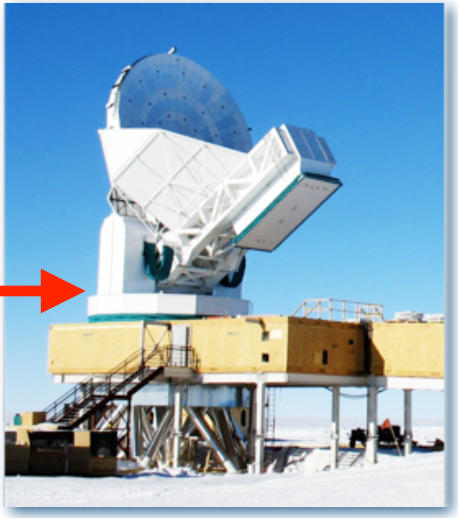


Mo/Au proximity effect 500mK T_C bilayer TES

FY11-13 Plan for CMB Thrust:

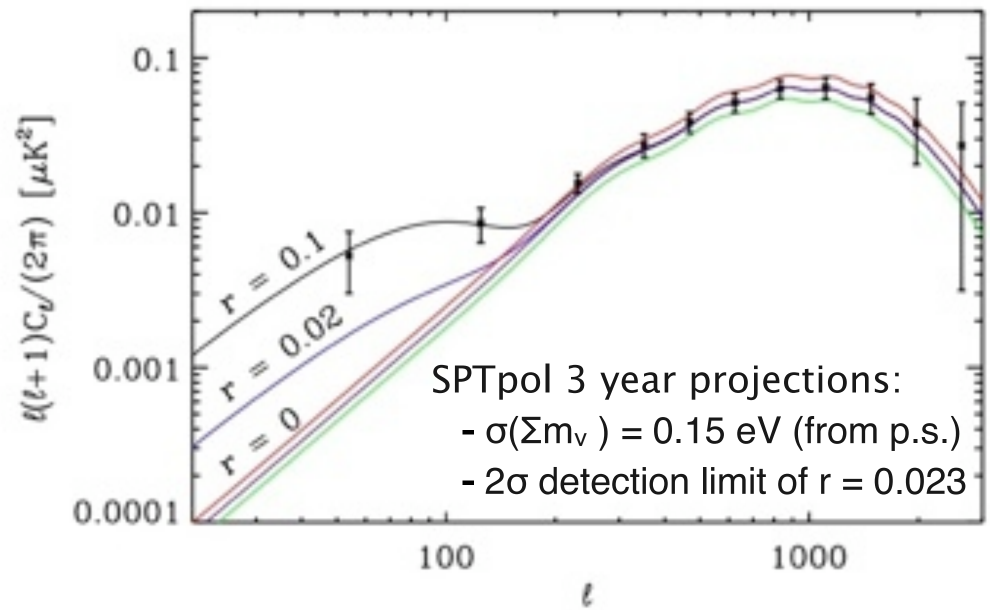






A) Deploy SPTpol (11/2011)

ANL providing 90 GHz channel and participating in SPTpol & ongoing dark energy data analysis.



Update from September 30 review

Achieved final Argonne 90 GHz TES design for November 2011 deployment. Now in production.

- Fully engineered TES transition R(T) for readout stability and linear operation.
- Fully dark and optically tested dual-pol, 90 GHz detector
  - excellent coupling (> 90 %)
  - good polarization purity
  - background limited noise
  - Completed design of focal plane construction, assembly, readout, and wiring.
  - Now in production
- On schedule for initial Nov 2011 deployment with 192 ANL 90 GHz pixels (384 detectors).